On the higher order nonlocal effect of relativistic ponderomotive force in high intensity lasers

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Ponderomotive force (light pressure) is a central concern in a wide class of nonlinear plasma physics. An example is that associated with high power lasers whose intensities lie in the nonlinear relativistic regime, where the force dominates the particle motion and then the laser-plasma interaction. Therefore, designing laser field patterns and controlling the ponderomotive force are of specifically importance.

The ponderomotive force has been formulated as being proportional to the local gradient of the field amplitude by using the averaging method. This results from the first order perturbation for the expansion parameter ε, the ratio between the excursion length and scale length of the field amplitude gradient. However, the neglected higher order terms can become important for the delicate control of laser profiles. For instance, in a flat-top beam profile which has an advantage in various applications, the gradient of the field amplitude near the axis is diminished, so that the higher order terms, which represent the effect of nonlocal particle motion, capture the dynamics.

Here, we explore the ponderomotive theory including the nonlocal effects up to ε^3 based on the noncanonical Lie perturbation method [1, 2]. We derived a new formula of relativistic ponderomotive force which depends not only on the local field gradient, but also on the curvature and its variation. We have applied the formula to study the particle motion in the flat-top super Gaussian beam discussed above and confirmed that the higher order terms derived here dominate the dynamics. The idea of nonlocal ponderomotive force can also be applied in deriving the equations which describe the laser propagation in plasmas such as the nonlinear Schrödinger (NS) equation. Namely, the NS equation can be generalized including such higher spatial derivatives and nonlinearity which are expected to exhibit new nonlinear and nonlocal dynamics.

[1] J. R. Cary and R. G. Littlejohn, Ann. Phys. **151**, 1 (1983).
[2] N. Iwata, Y. Kishimoto and K. Imadera, Plasma Fusion Res. **6**, 2404105 (2011).